Geothermal Systems

System Types, Applicability and Environmental Impacts

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Fig. 01 Currently, geothermal energy is most commonly used to heat homes in extremely cold climates.

Introduction

Wind power and solar power systems have become part of common knowledge and conversation over the past few years. While these provide excellent sustainable options of energy production, geothermal energy systems are just as efficient and economical.

Solar and wind energy collectors are site specific. Photo-voltaic cells will not harness much energy in northern locations. The area required to collect wind power can not be found in large cities. However geothermal systems do not take up buildable ground level space nor are they location or climate specific. The earth has a generally constant temperature throughout the year which can be used in geothermal systems to benefit all sites.[1] Figure 02 shows the average ground temperatures across the United States. At six feet below the surface, temperatures range from 45 to 75 degrees depending on the elevation.

If all geothermal resources were combined, enough energy would be produced to provide all of the electricity needs in the United States.[2] Why then is this option employed much less commonly and rarely even involved in sustainable system conversations?

Much of this report is based on information presented by Bruce L. Cutright. Throughout the course of his extensive research, he has come to the logical conclusion that the capabilities and affordability of geothermal systems are largely underestimated. A lack of publicly available information is the main reason that these systems are not widely used. With improvements in technology and decreases in installation cost, this is now not only a cost-competitive system but could have a great impact on the future of worldwide energy usage.

Some of the most important yet often underestimated effects of geothermal systems are their environmental impacts beyond energy related matters. Possible consequences to the earth and ecosystem from drilling to such great depths, involving natual water sources into the process, and the activity of heat transfers underground are necessary to understand in order to fully evaluate geothermal systems.

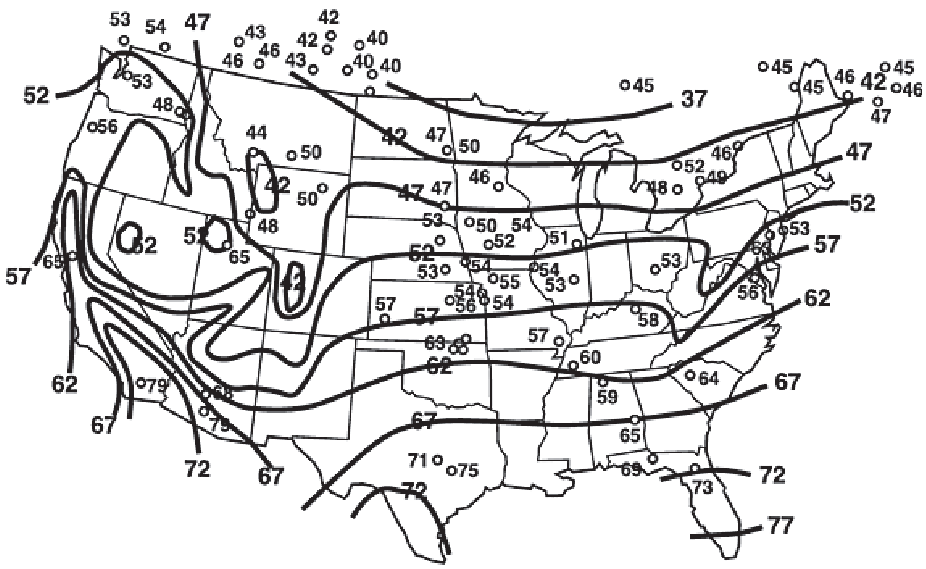

Fig. 02 Mean annual earth temperature observations at individual stations, superimposed on well-water temperature contours

What is Geothermal Heating and Cooling?

Geothermal Heating and Cooling Systems provide space conditioning, and in some cases water heating. These systems work by moving heat, rather than by converting chemical energy to heat like in a furnace. A typical system has three major parts: a series of underground pipes (the geothermal loop), a geothermal heat pump to move heat between the building and the ground, and a distribution system (a fan and duct work, a radiant floor, etc). When heating the building, the system operates by circulating a fluid through the loop and drawing heat from the soil. The fluid is then pushed through the heat pump inside the building and moved through a heat exchanger. When cooling a building, the process is reversed in order to pull heat out of the building. In open-loop systems, this heat is discharged into the outside air, while in closed-loop systems, the heat is transferred into the soil. This is possible due to the relatively constant temperature a few feet below the earth's surface, which ranges from between 45º and 70º (data from www.geoexchange.com). In the winter, the earth is used as a heat source, and in the summer, it acts as a heat sink.[3]

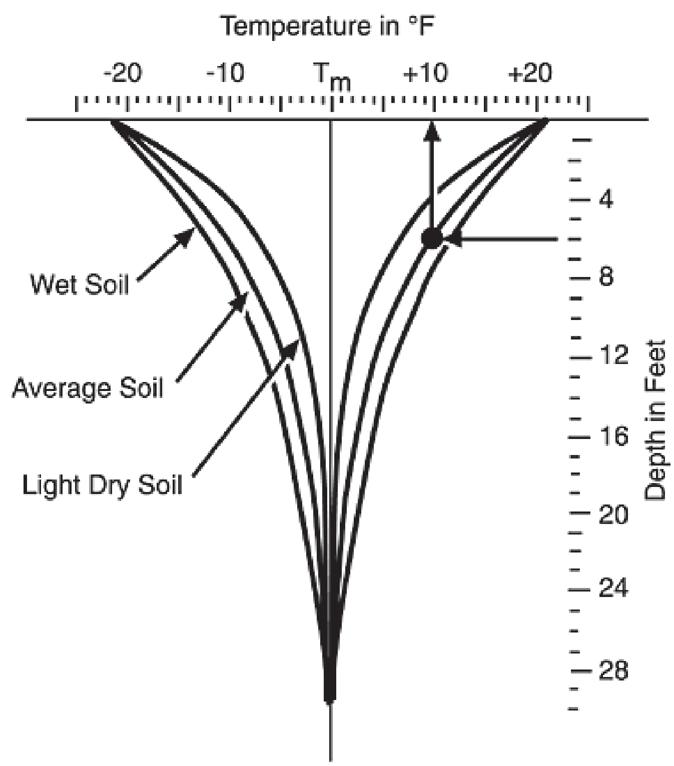

Fig. 03 Amplitude of seasonal soil temerature change as a function of depth below ground surface

Energy Sources, Systems and Technological Advances

The energy for geothermal systems may be derived from a number of sources: from magmatic or hydrothermal areas, from geopressured zones or high-heat flow zones using co-produced fluids from active or abandon oil or gas wells, and from hot dry rocks located in deep geologic zones having high heat flow.

There are two primary types of systems: ground source or groundwater source heat exchange systems, and enhanced geothermal systems, or EGS. The system most commonly used today is the ground source heat exchange system, because while subsurface conditions vary, a viable ground source heat exchange system can be designed for nearly any geologic conditions. Ground source systems can be either open- or closed-loop. In most open-loop systems, well water is drawn to the heat exchanger, and then discharged into a separate well, a field, or a body of water. In a closed-loop system, the same fluid is repeatedly moved through a continuous loop of pipes. In either case, the initial capital cost is between 30-50% higher than that of a conventional heating or cooling system.

Advances in drilling technology have made 8-10km deep holes possible due to polycrystalline diamond compact bits and slim-hole drilling. Advances in controlled fracture development have made enhanced geothermal systems practical. Advances in Binary-Cycle Heat Exchange Systems have made 100 degree Celsius heat sources economical.[4]

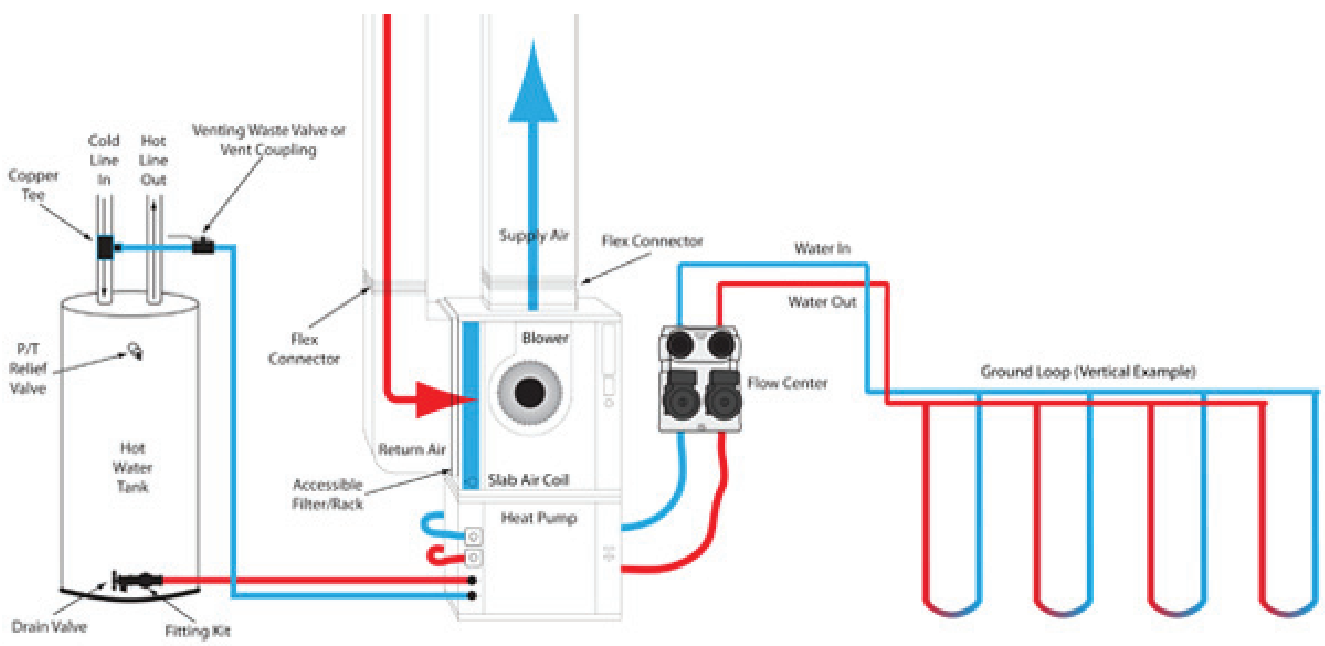

Fig. 04 Illustration of geothermal cooling cycle using a closed loop system.

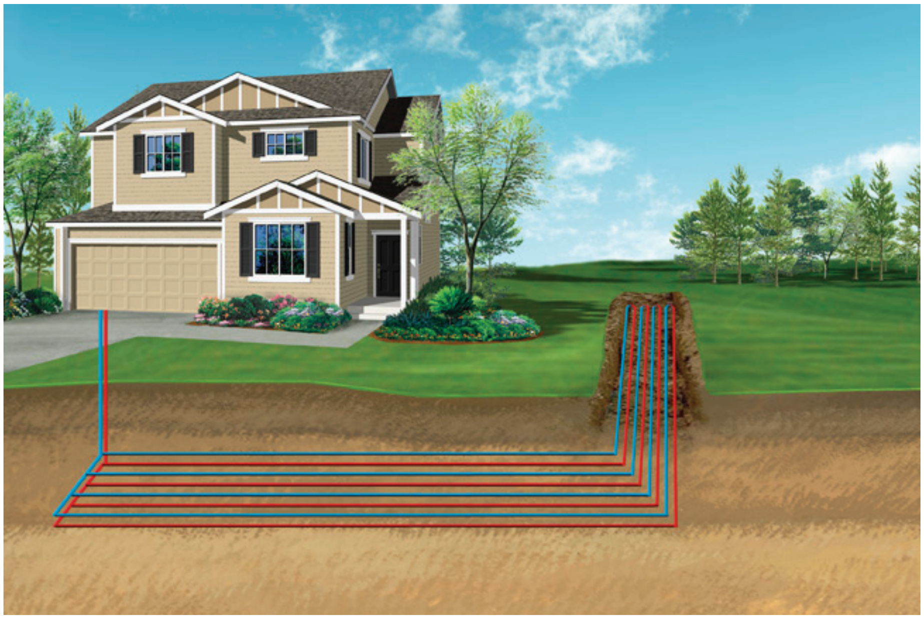

Fig. 05 A horizontal loop geothermal system. Loop installers use excavation equipment such as chain trenchers, backhoes and track hoes to dig trenches approximately 6-8 feet deep. Trench lengths range from 100 to 300 feet, depending on the loop design and application.

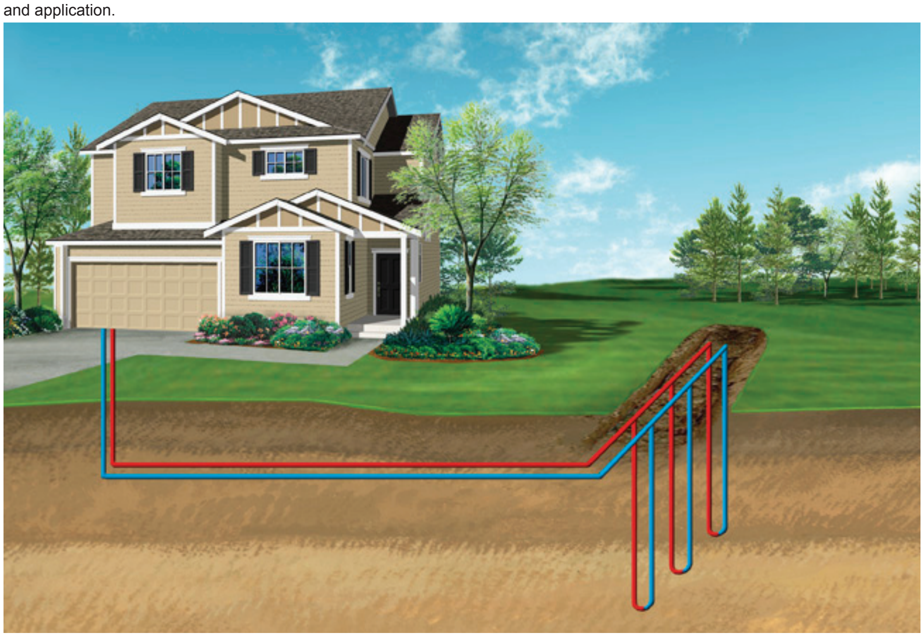

Fig. 06 A vertical loop geothermal system. A drilling rig is used to bore holes at of depth of 150 to 200 feet. A U-shaped coil of high density pipe is inserted into the bore hole. The holes are then backfilled with a sealing solution.

Fig. 07 A pond loop geothermal system. The system uses coils of pipe typically 300 to 500 feet in length. The coils are placed in and anchored at the bottom of the body of water.

Fig. 08 An open loop geothermal system. This system can be installed if an abundant supply of high quality well water is available. A proper discharge area such as a river, drainage ditch, field tile, stream, pond, or lake must be present.

Efficiency

Geothermal systems create positive energy, meaning that they produce higher quantities of energy than they require to operate.

Each kilowatt hour that geothermal heat pump systems consume leads to the production of three to six kilowatt hours of heat. The same efficiency rates apply to groundwater source heat pumps. This is due to the fact that these systems are only using energy to move around fluids and not to generate heat.[5]

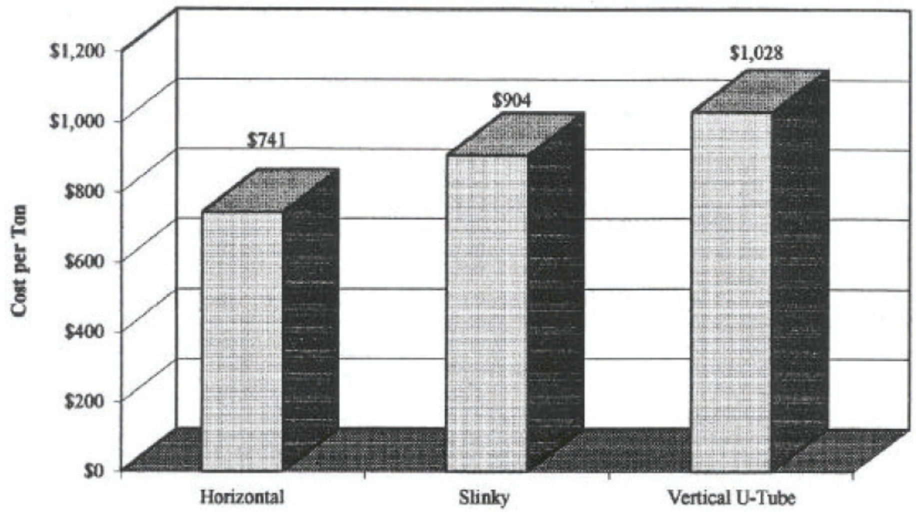

Fig. 09 Installed loop cost per ton of capacity as of 1995.

Economics

Overall Cost

Geothermal systems have high initial costs. The highest component of this cost is the ground loop. Figure 09 lists prices per ton of capacity for different ground loop types. On average, Ground Source Heat Pumps cost a total of $2,500 per ton of capacity.[6]

Some of the increased costs can also be attributed to the fact that there is limited competition in this market. However, over the past thirty years, improvements in drilling technology, advancements in binary-cycle heat exchange systems and advances in controlled fracture development have greatly increased the affordability of these systems.

Drilling does add heavily to the overall cost. Geothermal systems that are installed at depths that are no deeper than one hundred meters or what would be part of the normal construction process are considered easily accessible depths This is the range of depth where geothermal heat pumps are applicable.[7]

Maintenance costs are relatively low. There are fewer mechanical parts than traditional heating and cooling systems, and most components are underground and therefore sheltered from weather. The piping used in these systems lasts an average of twenty five to fifty years. Additionally, geothermal systems are LEED recognized and Energy Star issues rebates for some of the costs of installing a geothermal system.

Cost Comparison with Alternative Systems

The initial costs of the systems are approximately 30-50% higher than a regular heat pump system

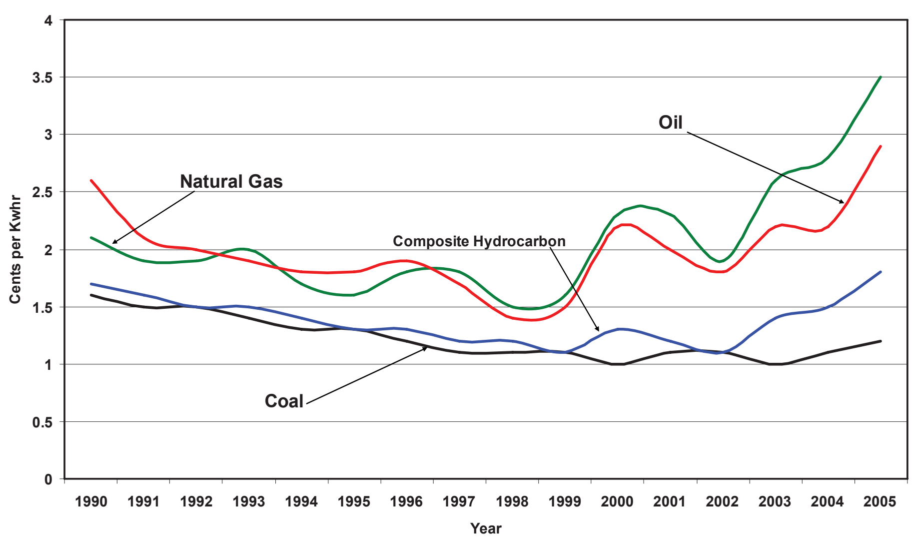

Fig. 10 Cost, in Cents per KWhr, for Power Generation from Hydrocarbon Sources.

with air conditioning.[8] However throughout the course of operation and maintenance, savings can amount to 40% according to the U.S. Environmental Protection Agency.

By using these systems, major conventional equipment is eliminated which reduces cost and size needed in the buiding. The boiler, chiller, complex controls, mechanical room size, added structural roof support, exterior heat exchange system and roof penetration and access are no longer needed. Additions include ground heat exchanger, heat pumps, large circulation pumps (which are all underground) and possibly larger air ducts and partial pipe insulation.[9]

Environmental Implications

Positive Environmental Effects

A study conducted by the U.S. E.P.A. concluded that geothermal systems have the lowest life cycle cost of all currently available heating and cooling systems. They consider geothermal heat pumps to be the most environmentally clean, energy- and cooling systems on the market.[10]

Geothermal systems positively effect the environment because they:
- reduce dependence on foreign oil as they are “homegrown”

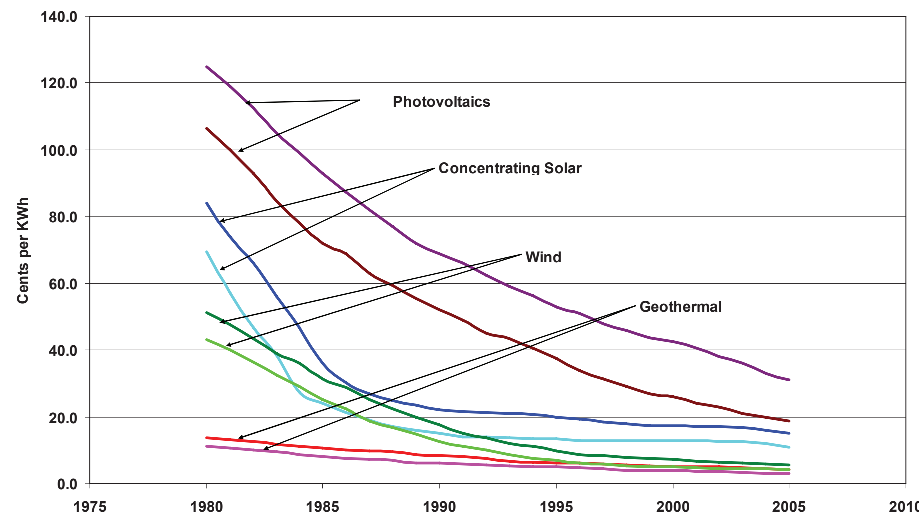

Fig. 11 Upper and Lower Cost Range of Energy for Alternative Energy Sources, in Cents per KWh

Levelized Cost of Electricity Analysis (Source: Credit Suisse 2009)	*High Case*	*Base Case*	*Low Case*	*Minimum*
Solar Photovoltaic (crystalline)	$201	$153	$119	$119
Solar Photovoltaic (Thin Film)	$180	$140	$110	$110
Fuel Cell	$117	$90	$72	$72
Solar Thermal	$126	$90	$69	$69
Coal	$66	$55	$46	$46
Natural Gas (CCGT)	$64	$52	$40	$40
Nuclear	$64	$62	$35	$35
Wind	$61	$43	$29	$29
Geothermal	**$59**	**$36**	**$22**	**$22**
Conservation/Efficiency	$30	$15	$0	$0
(figures in dollars per MWhr)				

Fig. 12 Cost, in dollars per MWhr, for varying power generation systems

efficient, and cost-effective heating

- provide a consant source of energy twenty four hours a day
- can be obtained without burning any fossil fuels

Negative Environmental Effects

Although geothermal systems produce zero emissions locally, the electricity needed to run them often contributes to harmful carbon emissions. Therefore their true impact on the environment needs to be evaluated with the inclusion of the sourse of their electric suppply. Also, the fluid used to run through the closed loops contained chlorodifluoromethane, an ozone depleting substance, until recently. This product is now being phased out in favor of a non-toxic fluid.

Depending on the soil and rock conditions of a specific location, the pumping of fluids can cause tensile or shear failure in the rock leading to seismic activity. In Basel, Switzerland (an earthquake prone zone), enhanced geothermal systems lead to a eathquake with a magnitude of 3.4 during the beginning of 2007. It has been argued that these occurances can be greatly reduced through predictive siting techniques.

Open-loop systems which require deep drilling and draw their water from a well may contribute to the depletion of acquifers, water shortages, contamination of groundwater and soil errosion issues. In Germany, the town of Staufen im Breisgau has been experiencing considerable ground level shifts since the Fall of 2007 when deep drilling was conducted to accommodate a geothermal system. At first the town sank by a couple of centimeters, and by 2008 it had risen by about five inches. Research has concluded that the official cause of these rapid level changes is from the mineral anhydrite transforming into gypsum. This happens when anhydrite comes into contact with

Estimated U. S. Geothermal Resource Base to 10km Depth by Category

(Modified from "The Future of Geothermal Energy, MIT 2006)

Category of Resource	***Thermal Energy, in ExaJoules (1EJ = 10^{18} J) High-Low Range***		***Thermal Energy in Barrels of Oil Equivalent High-Low Range***	
Hydrothermal	**2.40E+03**	**9.60E+03**	**4.13E+11**	**1.65E+12**
Co-Produced Fluids	**9.44E-02**	**4.51E-01**	**1.62E+07**	**7.76E+07**
Geopressured Systems	**7.10E+04**	**1.70E+05**	**1.22E+13**	**2.92E+13**
US Annual Primary Energy Consumption (2008)	**94.14**		**1.81E+10**	

COMPARISON OF FOSSIL FUEL EXTRACTABLE RESERVES TO GEOTHERMAL GEOPRESSURED/CO-PRODUCED FLUIDS EQUIVALENT ENERGY RESERVES

Source	**Estimate of Extractable Reserves**	**Reference**
Canadian Tar Sands	**300 billion barrels of oil equivalent**	**Edwards, 1997**
Orinoco Heavy Oils	**267 BBLSOE**	**Edwards, 1997**
Green River Shales	**139 BBLSOE**	**Edwards, 1997**
U. S. Proven Reserves of Crude Oil	**21.3 BBLSOE**	**EIA 2008**
Geothermal Resources	**29,200 BBLSOE (29.2 x 10^{12} BLSOE)**	**Blackwell, 2006**

Fig. 13 Chart displaying efficiency of geothermal systems

water. The common belief is that drilling broke into a layer of high pressure groundwater and exposed stata of the earth to water that were not originally in contact with the element.[11]

Case Studies

Austin, Texas Schools

The Austin Independent School District was the very first school district in the nation to install GeoExchange geothermal systems on a broad scale. Since 1989 almost all new heating and cooling system installations in Austin schools have been GeoExchange. Total estimated savings were around 25% in energy costs according to a report from 1997. Figure 14 shows energy savings for four AISD schools.

In all cases, the system has improved energy performance. This is regardless of the school size, the previous type of system, or the individual conditions surrounding installation and operation. At Pease Elementary, for instance, the system was installed under a completely paved area as a retrofit project, and energy savings are still estimated at 25%.

The installation costs for Pease Elementary are as follows:

- Heat Pumps: $92,000
- Loop Wells: $96,000
- Other/Installation: $86,170
- Utility Rebate: $5,470 ($2,000 per kW on heat pump nameplate)
- Total: $268,700

Besides savings in energy, AISD has also noticed an improvement in maintenance. With a little over one hundred schools in the district, stocking parts like chillers, boilers and convectors for traditional systems was quite a difficult task. By standardizing the GeoExchange units, maintenance was majorly reduced. Replacement and repair can be done classroom by classroom as each room's unit is individually connected to a well system. However this method did add to the installation cost.

Teachers and students reported satisfaction with the system and appreciate the individual control each room has over the temperature.[12]

Conclusion

Although geothermal systems still do not draw the same level of attention as do solar and wind energy systems, their use is increasing for multiple reasons. Rapidly improving efficiency caused by technological advances in drilling and heat exchange have expanded the area in which these systems can be used, along with how well they perform. Meanwhile, heightened awareness of their benefits through recognition in programs like LEED and Energy Star have demonstrated the reduced environmental impacts of the systems, as well as their low maintenance costs and high return values. As additional high-profile examples of geothermal systems – such as that of the Austin Independent School District – are built, the use of these systems should only increase.

School	Pease Elementary	Brooke Elementary	Govalle Elementary	Bailey Middle
New/Retrofit	Retrofit	Retrofit	Retrofit	New
Square feet	39,162	51,605	89,319	approx. 200,000
Old System	Roof Packaged	not available	Chiller, gas	none
Capacity	90 tons	approx. 150 tons	approx. 230 tons	512 tons
Est. $ Savings	25%	25%	20%	not available
kWh/sq ft	8.3	9.6	8.5	not available
Students	298	346	626	1614
Year Installed	1994	1993	1994	1992

Fig. 14 Installation and cost information for four AISD schools.

Notes

1.Geo4VA, “Seasonal Temperature Cycles”, Virginia Tech, http://www.geo4va.vt.edu/A1/A1.htm, accessed November 2009.

2. Bruce L. Cutright, “The Case for Geothermal Energy” (Presentation for the Meadows Seminar at the University of Texas in Austin, Texas, October 29, 2009).

3. Geothermal Heat Pump Consortium “Common Questions.” 2006. http://www.geoexchange.org/resources/common-questions.html, accessed November, 2009.

4. Bruce L. Cutright, “The Case for Geothermal Energy” (Presentation for the Meadows Seminar at the University of Texas in Austin, Texas, October 29, 2009).

5. Consumer Energy Center, “Geothermal Heat Pumps”, California Energy Commission, http://www.consumerenergycenter.org/home/heating_cooling/geothermal.html, accessed November 2009.

6. Steve Kavanaugh et al., “Cost Containment for Ground-Source Heat Pumps” (Final Report submitted to the Alabama Universities-TVA Research Consortium and the Tennessee Valley Authority, December 1995).

7. Bruce L. Cutright, “The Case for Geothermal Energy” (Presentation for the Meadows Seminar at the University of Texas in Austin, Texas, October 29, 2009).

8. Steve Kavanaugh et al., “Cost Containment for Ground-Source Heat Pumps” (Final Report submitted to the Alabama Universities-TVA Research Consortium and the Tennessee Valley Authority, December 1995).

9. Consumer Energy Center, “Geothermal Heat Pumps”, California Energy Commission, http://www.consumerenergycenter.org/home/heating_cooling/geothermal.html, accessed November 2009.

10. Energy Star, “Geothermal Heat Pumps”. U.S. EPA, http://www.energystar.gov/index.cfm?c=geo_heat.pr_geo_heat_pumps, accessed November 2009.

11.SwissInfo with Agencies, “Man-Made Tremor Shakes Swiss City of Basel” SwissInfo, http://www.swissinfo.ch/eng/Man-made_tremor_shakes_Basel.html?cid=46232, accessed November 2009.

12. Geothermal Heat Pump Consortium, “Austin Independent School District, 1997”, GeoExchange, http://www.geoexchange.org, accessed November 2009.

Figures

Figure 01: About My Planet, “Geothermal Energy”, AmpBlogs Network, http://www.aboutmyplanet.com/alternative-energy/geothermal-energy/2009, accessed November 2009.

Figure 02: Geo4VA, “Seasonal Temperature Cycles”, Virginia Tech, http://www.geo4va.vt.edu/A1/A1.htm, accessed November 2009.

Figure 03: Geo4VA, “Seasonal Temperature Cycles”, Virginia Tech, http://www.geo4va.vt.edu/A1/A1.htm, accessed November 2009.

Figure 04: GeoComfort. Illustration of geothermal cooling cycle, 2008. http://geocomfort.publishpath.com/geothermal-technology (accessed November, 2009).

Figure 05: GeoComfort. Illustration of horizontal closed-loop geothermal system, 2008. http://geocomfort.publishpath.com/geothermal-technology (accessed November, 2009).

Figure 06: GeoComfort. Illustration of vertical closed-loop geothermal system, 2008. http://geocomfort.publishpath.com/geothermal-technology (accessed November, 2009).

Figure 07: GeoComfort. Illustration of pond loop geothermal system, 2008. http://geocomfort.publishpath.com/geothermal-technology (accessed November, 2009).

Figure 08: GeoComfort. Illustration of open loop geothermal system, 2008. http://geocomfort.publishpath.com/geothermal-technology (accessed November, 2009).

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References

Reference 01 Kavanaugh, Steve, Christopher Gilbreath, and Joseph Kilpatrick. 1995. Cost Containment for Ground-Source Heat Pumps. Final Report submitted to the Alabama Universities-TVA Research Consortium and the Tennessee Valley Authority, December.

Reference 02 Hughes, Patrick J. 2008. Geothermal (Ground Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers. Sponsered by EERE Geothermal Technologies Program and the U.S. Department of Energy, December.

Reference 03 Geothermal Heat Pump Consortium. Austin Independent School District, 1997. GeoExchange. http://www.geoexchange.org. Accessed November 2009.

Reference 04 Doherty, P.S., S. Al-Huthaili, S.B. Riffat and N. Abodahab. November 2003. Ground Source Heat Pump-Description and Preliminary Results of the Eco House System. School of the Built Environment, Institute of Building Technology, University of Nottingham.

Reference 05 Geo4VA. Seasonal Temperature Cycles. Virginia Tech. http://www.geo4va.vt.edu/A1/A1.htm. Accessed November 2009.

Reference 06 Bruce L. Cutright. The Case for Geothermal Energy. Presentation for the Meadows Seminar at the University of Texas in Austin, Texas, October 29, 2009.

Reference 07 Consumer Energy Center. Geothermal Heat Pumps. California Energy Commission. http://www.consumerenergycenter.org/home/heating_cooling/geothermal.html. Accessed November 2009.

Reference 08 Energy Star. Geothermal Heat Pumps. U.S. EPA. http://www.energystar.gov/

index.cfm?c=geo_heat.pr_geo_heat_pumps. Accessed November 2009.

Reference 09 Geothermal Heat Pump Consortium. Common Questions. 2006. http://www.geoexchange.org/resources/common-questions.html. Accessed November, 2009.

Reference 10 SwissInfo with Agencies. Man-Made Tremor Shakes Swiss City of Basel. SwissInfo. http://www.swissinfo.ch/eng/Man-made_tremor_shakes_Basel.html?cid=46232. Accessed November 2009.